Recent Charm Production and Neutrino Oscillation Results From CHORUS

Aysel Kayış Topaksu,
University of Çukurova, Adana

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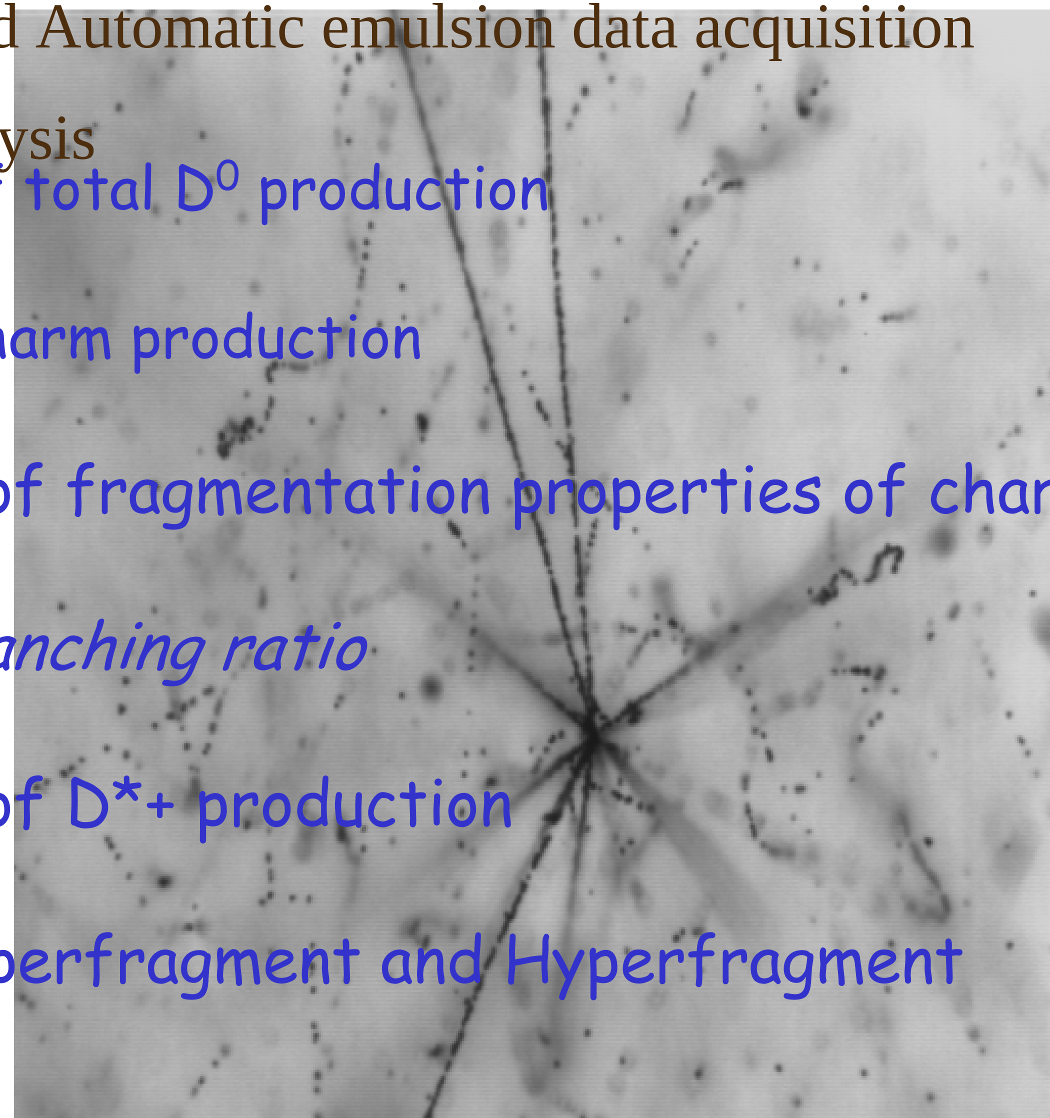
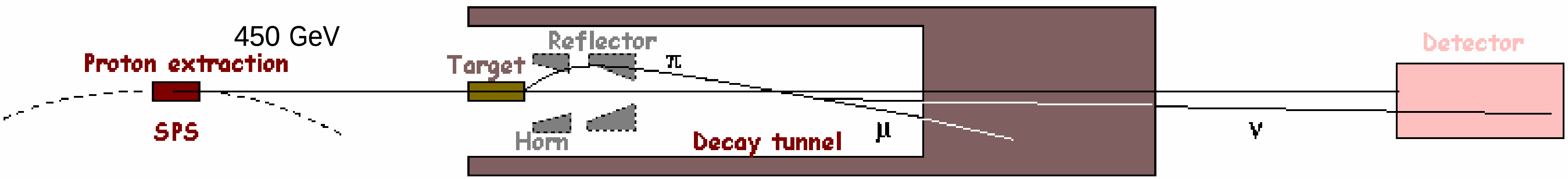
Outline

- CERN Neutrino Beam Line
- CHORUS detector and Automatic emulsion data acquisition
- Results on charm analysis
  - Measurement of total D^0 production
  - Anti-neutrino charm production
  - Measurement of fragmentation properties of charm
  - *$B\mu$: muonic branching ratio*
  - Measurement of D^{*+} production
  - Search for Superfragment and Hyperfragment
- Result on oscillation
- Conclusion



Neutrino beam

West Area Neutrino Facility at CERN SPS



CHORUS, NOMAD

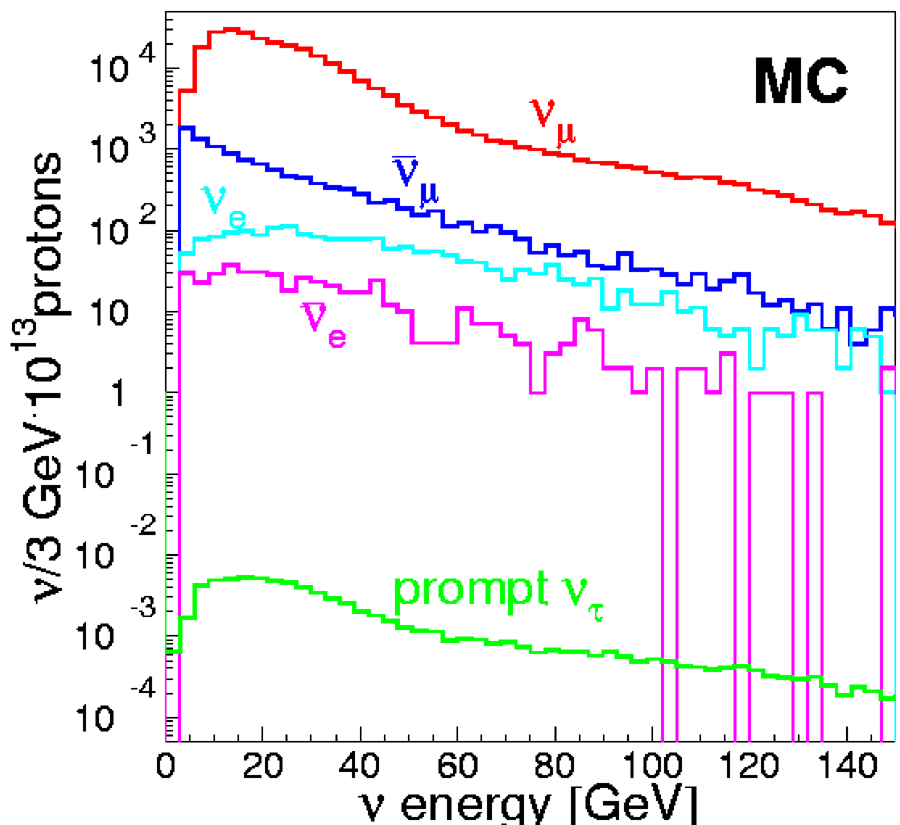
Wide Band Beam

- 5.06×10^{19} POTs (1994-1997)
- $\langle E\nu_\mu \rangle \sim 27$ GeV
- $\langle L \rangle \sim 0.6$ km

  $\langle L \rangle / \langle E \rangle \sim 2 \times 10^{-2}$ km/GeV

  $\rightarrow \Delta m^2 > 1$ eV^2

- Prompt ν_τ : negligible



CHORUS detector

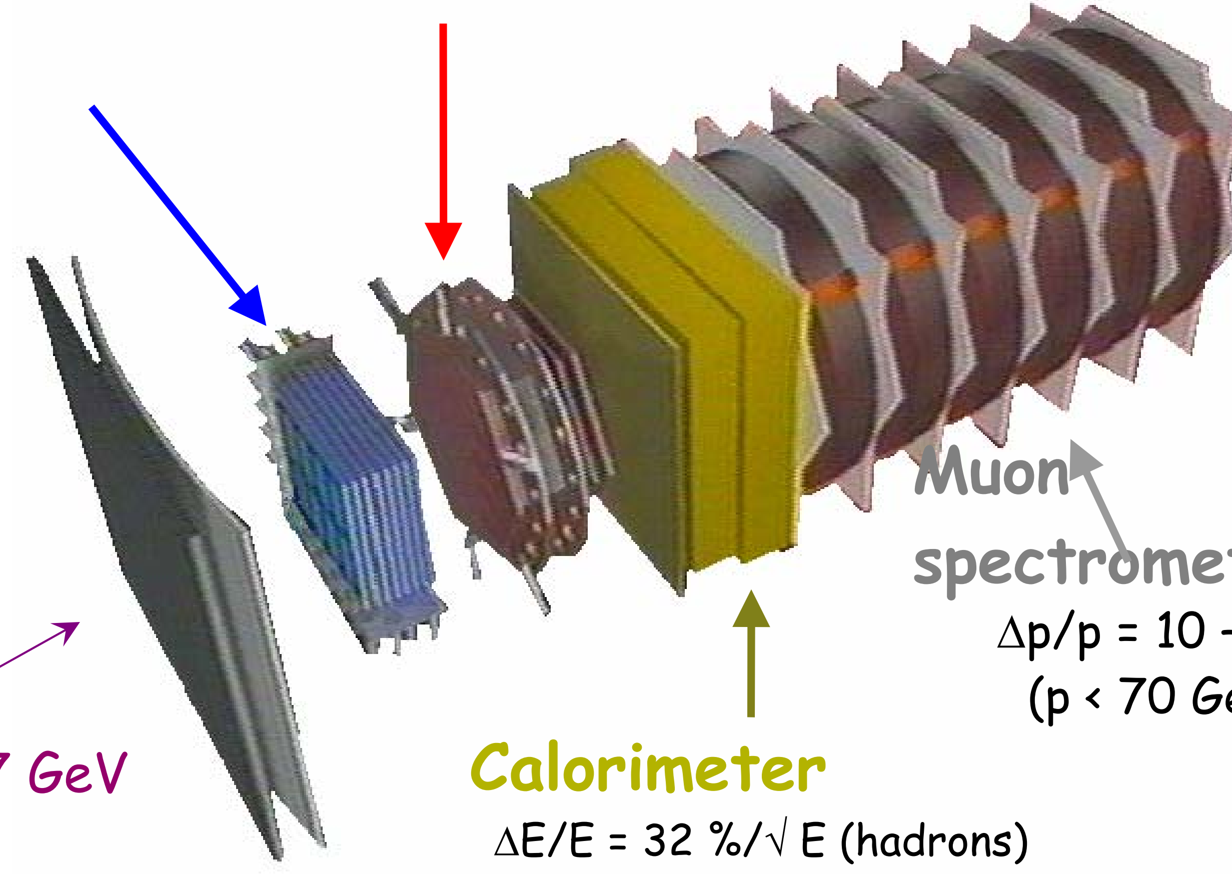
Active target

nuclear emulsion target (770kg)

scintillating fiber tracker

Air-core magnet

$\Delta p/p = 0.035\ p\ (\mathrm{GeV}/c) \oplus 0.22$



Muon spectrometer

$\Delta p/p = 10 - 15\%$

$(p < 70\ \mathrm{GeV}/c)$

$\nu_\mu \sim 27$ GeV

CERN SPS

Calorimeter

$\Delta E/E = 32\ \%/\sqrt{E}$ (hadrons)

$= 14\ \%/\sqrt{E}$ (electrons)

$\Delta\theta_h = 60$ mrad @ 10 GeV

Veto

Automatic emulsion data acquisition

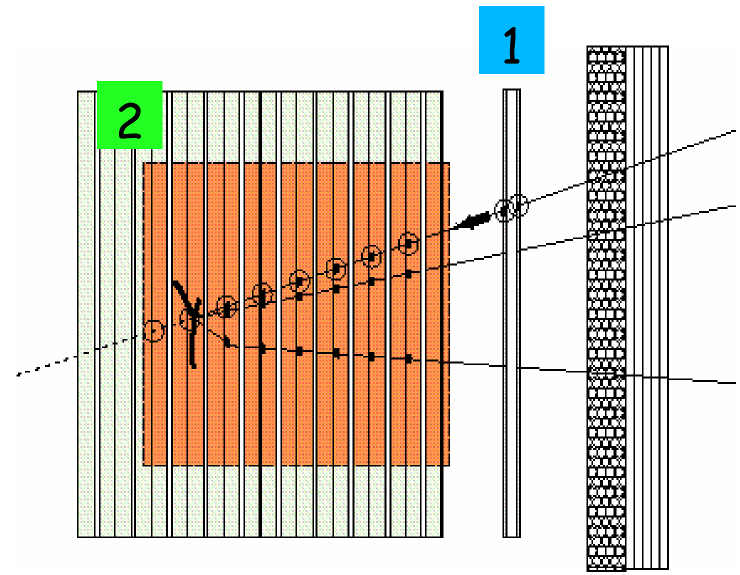
1 Location of ν interaction vertex guided by electronic detector.

2 Full data taking around ν interaction vertex called Netscan

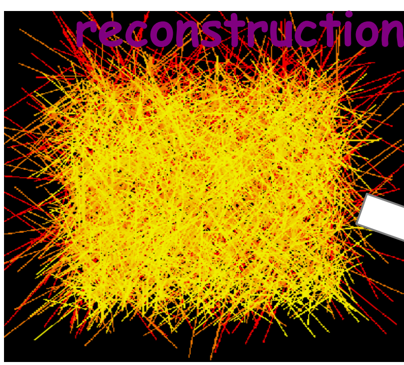
Volume : 1.5 x 1.5 mm^2 x 6.3 mm

Angular acceptance : 400 mrad

~ 11 minutes / event

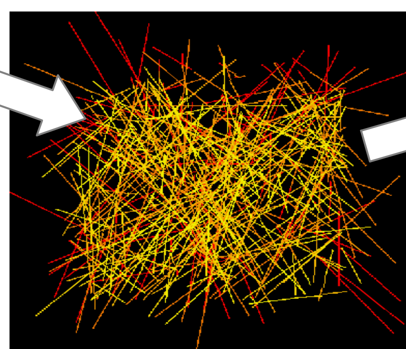


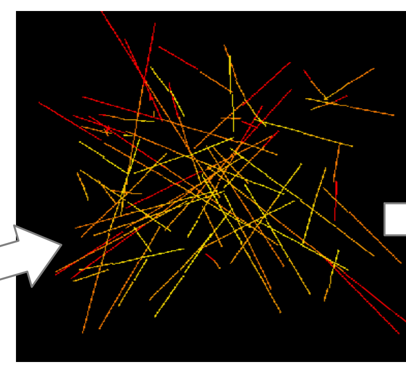
3 Offline tracking and vertex reconstruction



Track segments from 8 plates overlapped

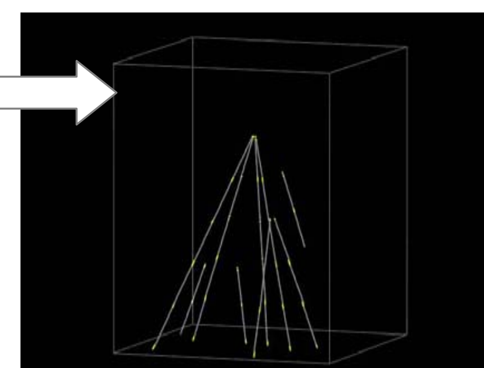
At least 2-segment connected tracks





Eliminate passing through tracks

Reconstruct full vertex topology

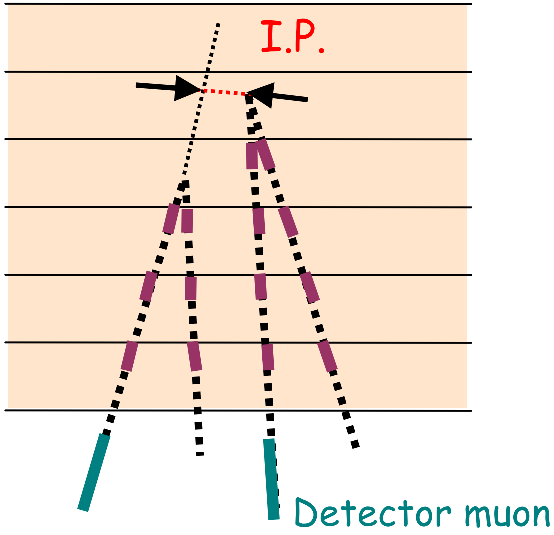


Measurement of D^0 production

Phys. Lett. B 527 (2002) 173, based on ~25% of statistics

Phys. Lett. B 613 (2005) 105, based on full statistics

NOW: full sample: ~ 95000 CC events



Candidate selection

- Primary track matched to detector muon
- Daughter track matched to detector track
- 3 ~ 13 μm < I.P. wrt. 1ry vtx < 400 μm

Confirmed D^0 sample

- 2 prong (V2) 819
- 4 prong (V4) 226

Selection efficiencies

- V2 : 0.561 ± 0.018
- V4 : 0.754 ± 0.027

$(D^0 \to V4) / (D^0 \to V2)$

$= 0.207 \pm 0.016 \pm 0.004$

D^0

Fully neutral D^0 decay mode:

BR4/BR2 - measured

BR4 = 0.1338 ± 0.0058 ➡ PDG

BR($D^0 \rightarrow$ neutrals) = 1-BR4 x(1+ BR2/BR4) = 21.8 ± 4.9 ±3.6% (6 prong negligible)

Total production cross section:

Relative detection efficiency D^0/CC = 0.88

$\sigma(D^0)/\sigma(CC) = (2.69 \pm 0.18 \times 0.13)\%$

Phys. Lett. B 604 (2004) 11-21

Charm production in antineutrino interactions

N_{μ^+} = 2704 ← "1μ spectrometer events"

N_{μ^-} ~ 95000

Selected events for visual insp= 81 ← Θ_{kink} > 50 mrad, F.L > 50 μm

found charm = 40

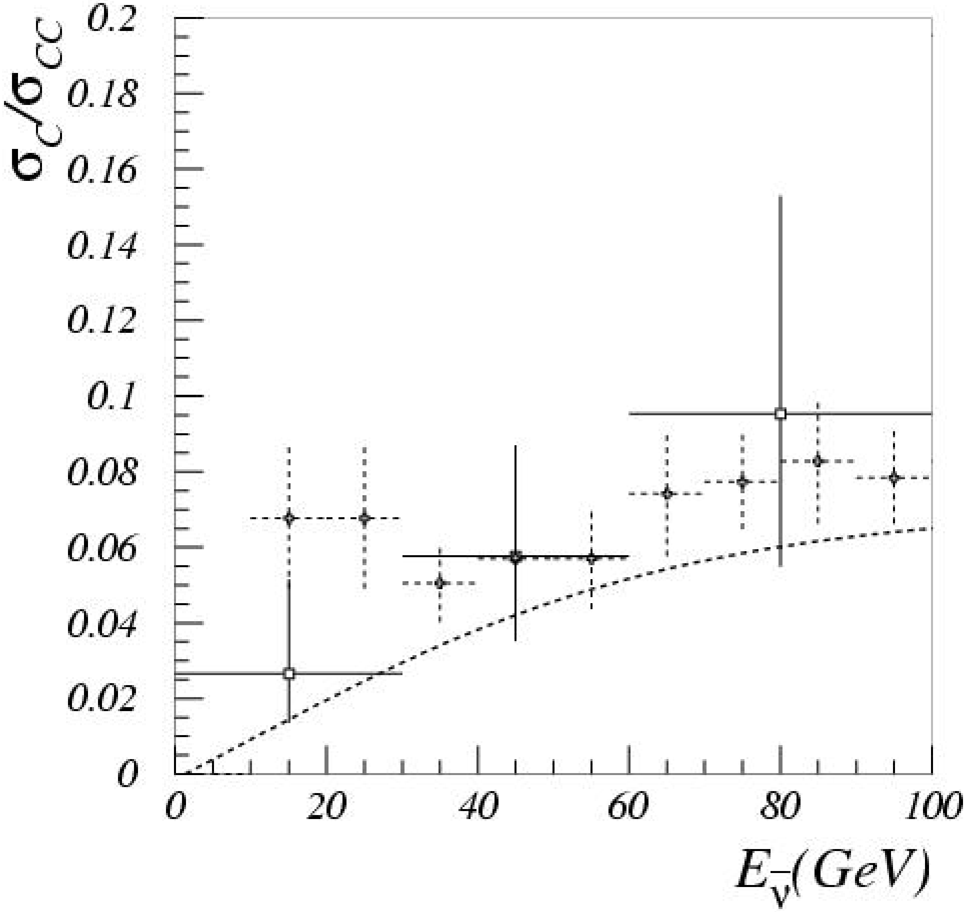
$\boxed{N^{\bar{\nu}_\mu}}$ = 4975 ± 187 ±53

$$\frac{f_{c^0}}{f_{c^-}} = 2.6^{+1.7}_{-1.2}\text{(stat)} \pm 0.8\text{(syst)}$$

$$\frac{\sigma(\bar{\nu} N \to \mu^+ \bar{c} X)}{\sigma(\bar{\nu} N \to \mu^+ X)} = (5.0^{+1.4}_{-0.9} \pm 0.7)\,\%$$

$\bar{\nu}_\mu$Charm

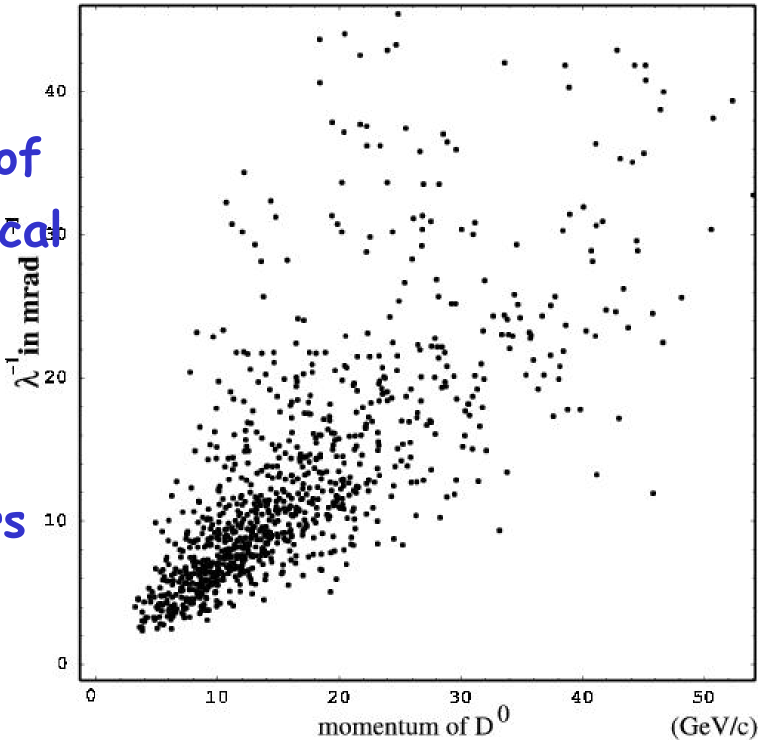
Charm production rate as a function of neutrino energy



Measurement of fragmentation properties of charm

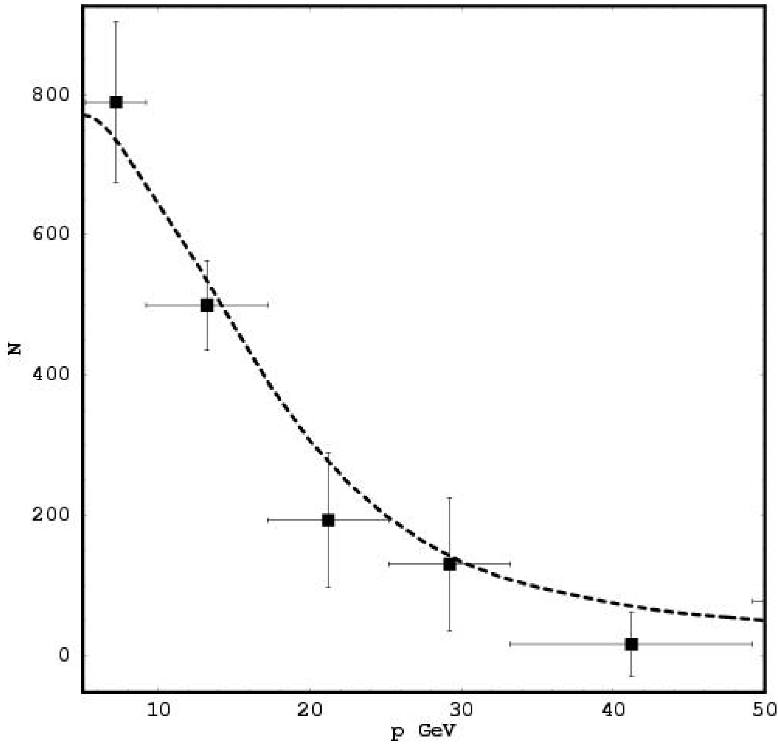
Measurement of D^0 momentum

Inverse of geometrical mean of opening angle of daughters



D Momentum

Use correlation between opening angle of decay daughters and charm momentum to obtain momentum dist.



Z-distribution

Fits to Collins-Spiller and Peterson:

$z = E_D / \nu$

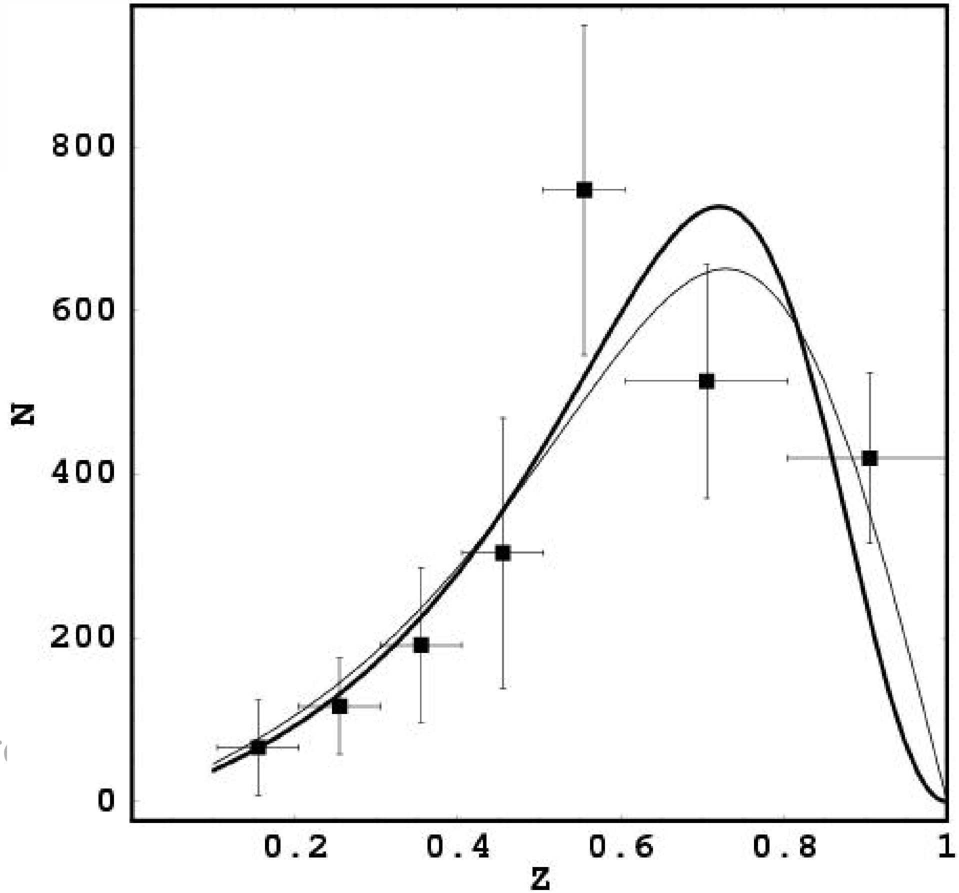
$$D_c(z) = N\left(\frac{1-z}{z} + \frac{\epsilon_c(2-z)}{1-z}\right)(1+z^2)\left(1 - \frac{1}{z} - \frac{\epsilon_c}{1-z}\right)^{-2}$$

$$D_p(z) = \frac{N}{z\left(1 - 1/z - \epsilon_p/(1-z)\right)^2}$$

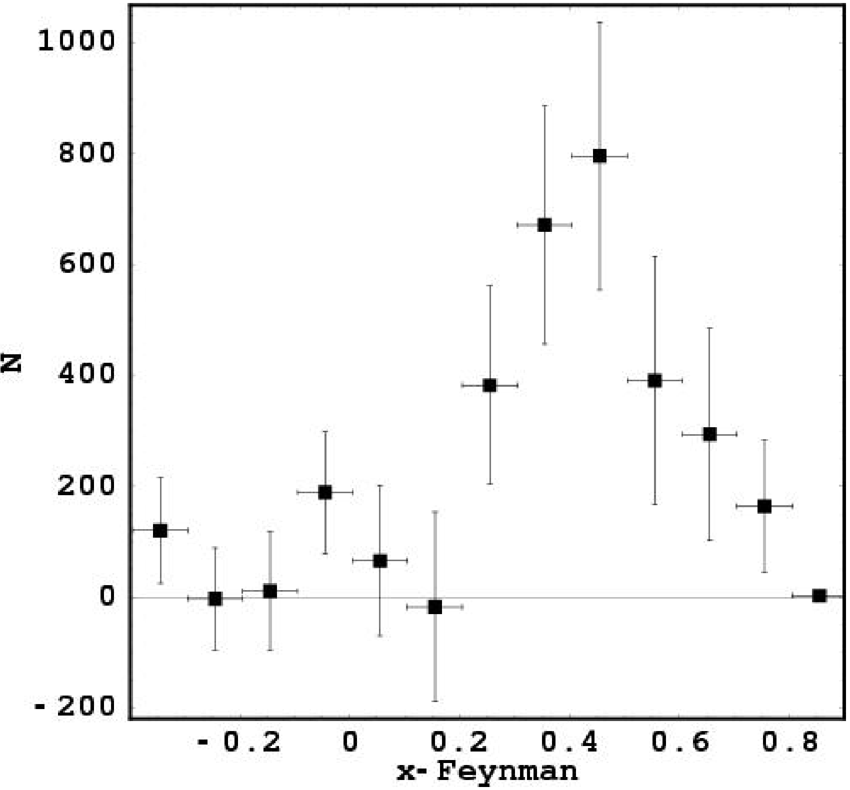
CHORUS:

Fit to Peterson formula

(dotted curve is MC model)



- Also an E531 measurement
- Indirect measurements from dimuon dat
  - CDHS, CCFR, CHARMII, NuTeV, CHORUS



Phys. Lett. B604 (2004) 145

Feynman x (x_F) -distribution

Most charmed particles are produced in the forward region

$$x_F = p_L / p_{max}$$

Experiments	$\langle z \rangle$	ϵ	$\langle x_F \rangle$	Asymmetry
E531[7]	0.59 ± 0.04	0.076 ± 0.014	—	0.620 ± 0.092
NOMAD[8]	$0.67 \pm 0.02 \pm 0.02$	$0.075 \pm 0.028 \pm 0.036$	0.47 ± 0.05	—
CHORUS	$0.58 \pm 0.06 \pm 0.03$	$0.13 \pm 0.02 \pm 0.03$	$0.37 \pm 0.04 \pm 0.01$	$0.88 \pm 0.15 \pm 0.0$
CDHS[2]	0.068 ± 0.08	$[0.02, 0.14]$	—	—
CCFR[4]	$0.56 \pm 0.0.03$	0.22 ± 0.05	—	—
CCFRR[5]	—	$0.40^{+0.25}_{-0.11}$	—	—
CHARM II[3]	0.66 ± 0.03	0.072 ± 0.017	—	—
BEBC[6]	$0.59 \pm 0.03 \pm 0.08$	—	—	—

Phys. Lett. B626 2005,24-34

B_μ: muonic branching ratio

Direct observation of the charm parent and its muon decay

Taking into account the new CHORUS measurement of
Br ($D^0 \rightarrow V0$)

$B_\mu = 7.3 \pm 0.8 \pm 0.2\%$

Dimuon events have larger visible energy
$E_{vis} > 30$ GeV

$\Rightarrow$ $B_\mu = (8.5 \pm 0.9 \pm 0.6)\%$

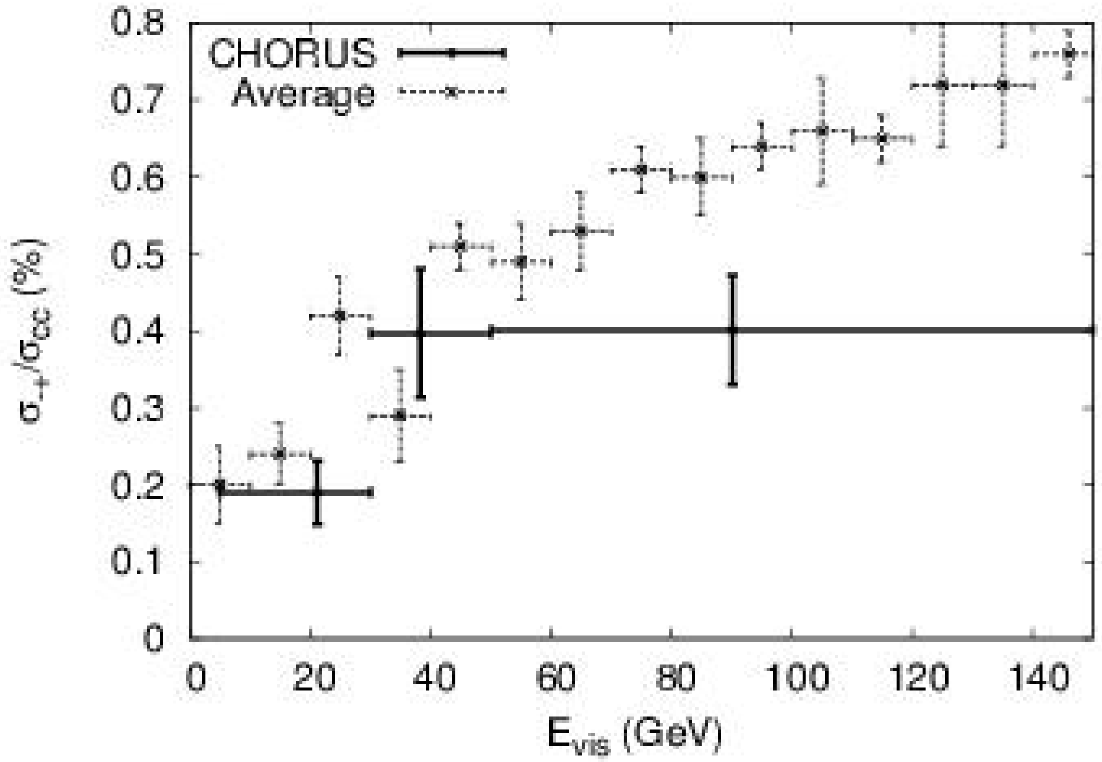
$B_\mu\, |V_{cd}|^2_{LO} = (0.474 \pm 0.027)\times 10^{-2}$
CDHS, CHARM II & CCFR averaged

$\Rightarrow$ $|V_{cd}|_{LO} = 0.239 \pm 0.046$

$0.221 < |V_{cd}| < 0.227$ at 90% CL
using CKM unitarity and 3 generations

The results takes into account the new CHORUS measurement of B(D0 → V0)≈22%

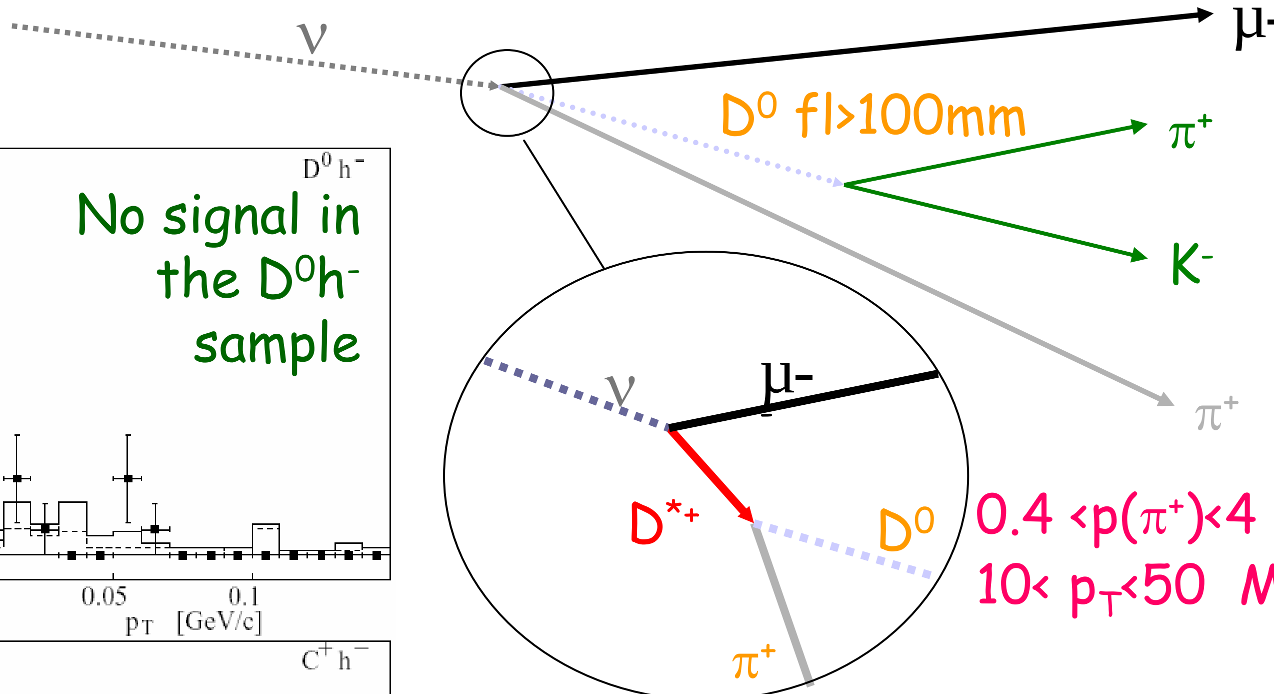
$$\frac{\sigma_{\mu^-\mu^+}}{\sigma_{cc}} = \left[3.16 \pm 0.34(stat)0.09(syst)\right] \times 10^{-3}$$



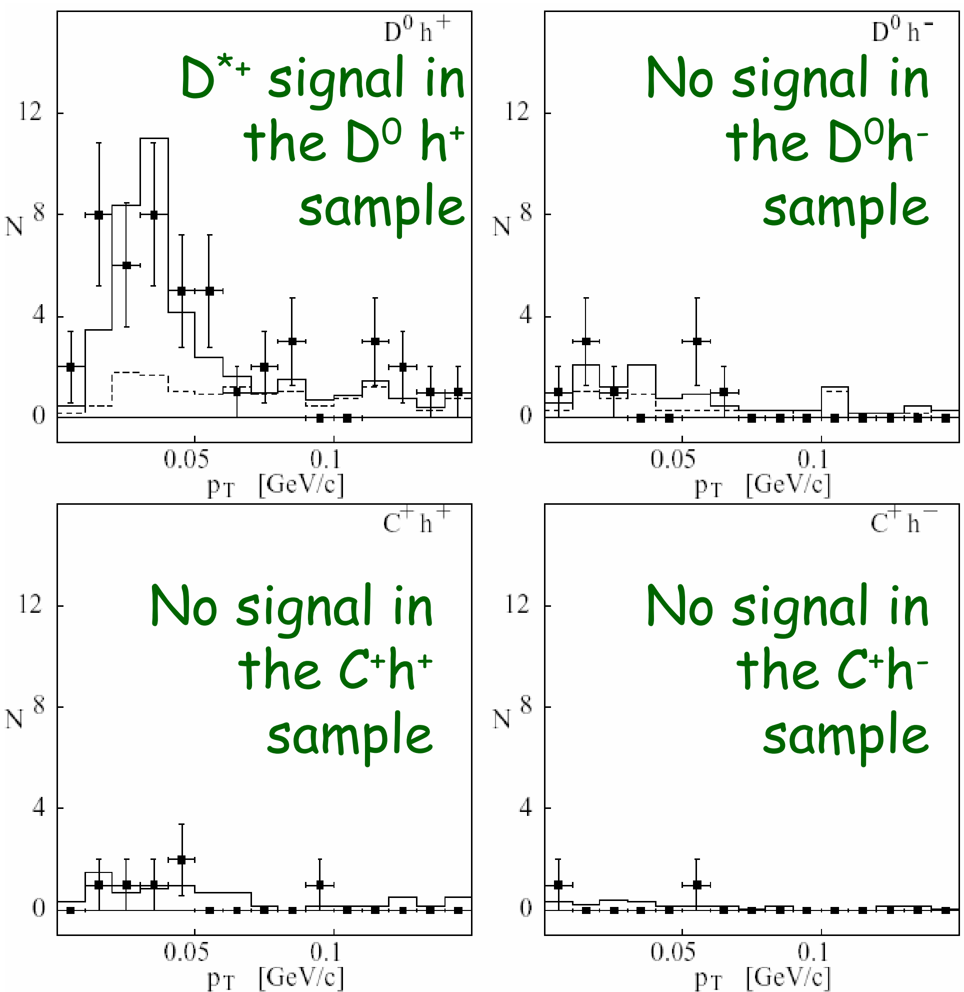
Measurement of D^{*+} production

Phys. Lett. B614 (2005) 155

Search for D^{*+} in the decay channel: $D^{*+} \rightarrow D^0 \ \pi^+$



$0.4 < p(\pi^+) < 4$ Ge
$10 < p_T < 50$ MeV



Number of observed events

Background prediction

(1)Shape of signal & background normalized to the observed events

(2-3-4) shape normalized to the total number of D^0 and C^+ respectively

Measurement of D^{*+} production

$Br(D^{*+} \to D^0 \pi^+)$=0.677±0.005 (PDG)

$$\frac{\sigma_{D^*}}{\sigma_{D^0}} = 0.38 \pm 0.09 \pm 0.05$$

$$\frac{\sigma_{D^*}}{\sigma_{CC}} = [1.02 \pm 0.25 \pm 0.15]\%$$

NOMAD	0.79 ± 0.17 ± 0.10
BEBC	1.22 ± 0.25 %
Tevatron	5.6 ± 1.8 % (higher energy)

assuming that prompt D^{*+} and D^{*0} production rates are equal we get

$$\frac{\sigma(D^0 \text{ from } \mathrm{D}^*)}{\sigma(D^0)} = 0.63 \pm 0.17$$

Search for Superfragments and Hyperfragments

Hyperfragments are nuclei with a strange baryon (lambda-zero)

Superfragments have a charmed baryon (lambda-c-plus)

Could be made in neutrino interactions

Expect decay within few microns from vertex

Search for events with a secondary vertex close to the primary vertex

Secondary vertex should have outgoing black track(s) and the decaying object should be black

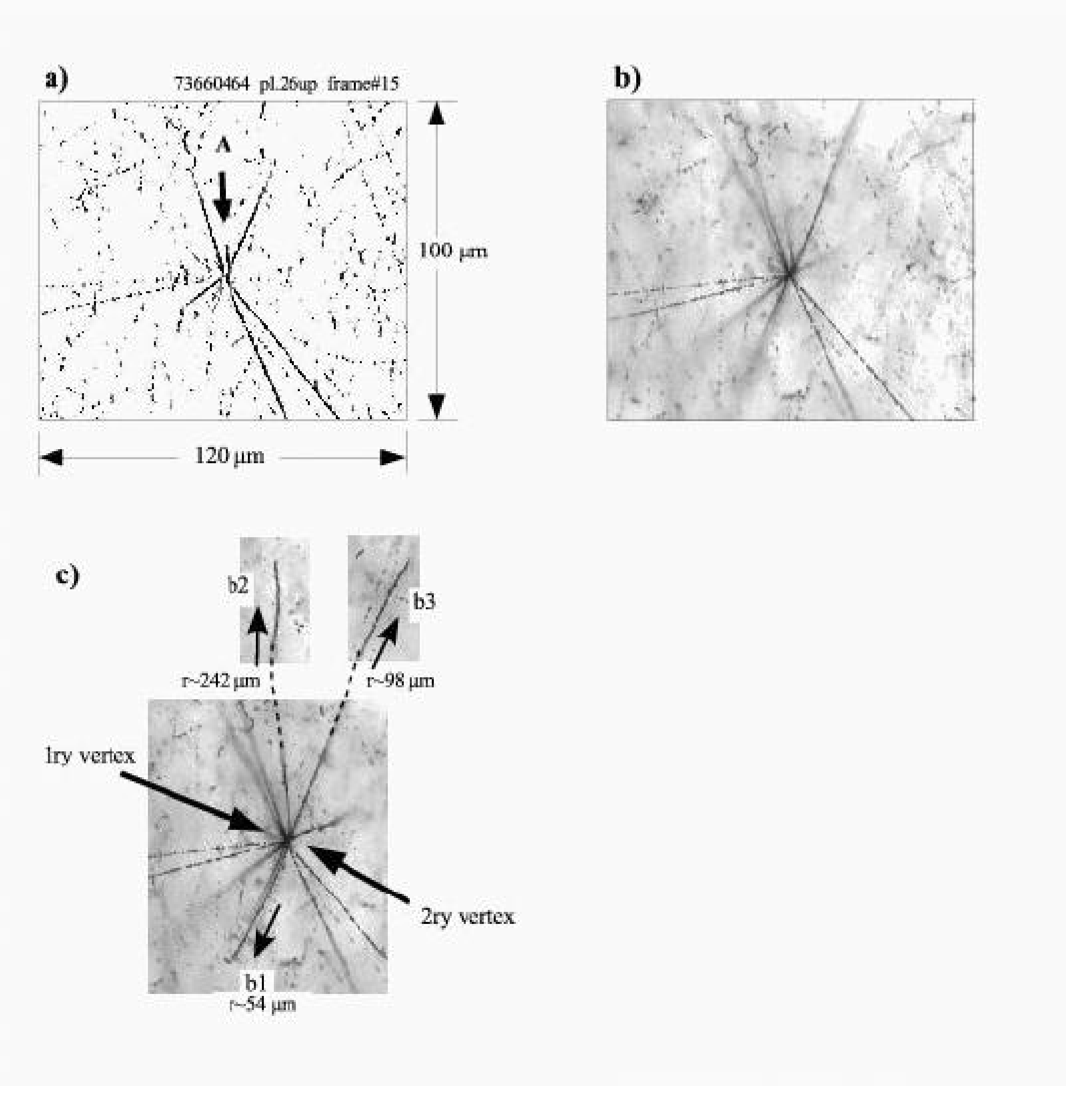
Distinguish hyper- from superfragments by kinematical analysis

Evidence for superfragments not convincing in litterature

look for "mesic decays", i.e. Pions in final state

Typical Candidate Event

A total of 28 non-mesic hyperfragments were found



Nuclear Physics B718, 2005, 35-54

Results

Hyperfragment production/ CC

$$\frac{\sigma(\nu_\mu \mathrm{A} \to \mathrm{HF(non\text{-}mesic)}\mu^- X)}{\sigma(\nu_\mu \mathrm{A} \to \mu^- X)} = (2.0 \pm 0.4(\mathrm{stat}) \pm 0.3(\mathrm{syst})) \times 10^{-3}$$

Superfragment production limit /CC

$$\frac{\sigma(\nu_\mu \mathrm{A} \to \mathrm{SF}\mu^- X)}{\sigma(\nu_\mu \mathrm{A} \to \mu^- X)} < 1.9 \times 10^{-4} \quad (90\%\mathrm{C.L.})$$

Using the Lambda_c production ratio

$(\sigma(\Lambda c)/\sigma(CC) = (1.54 \pm 0.35(\mathrm{stat}) \pm 0.18(\mathrm{syst})) \times 10^{-2})$

$$\frac{\sigma(\nu_\mu \mathrm{A} \to \mathrm{SF}\mu^- X)}{\sigma(\nu_\mu \mathrm{A} \to \Lambda_c^+ \mu^- X)} < 1.3 \times 10^{-2} \quad (90\%\mathrm{C.L.})$$

Oscillation Analysis

- ✓ Decay mode considered

  i)- $\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau$ ii)- $\tau^- \rightarrow h^-(n\pi^0)\nu_\tau$, iii)- $\tau^- \rightarrow 3h^-(n\pi^0)\nu_\tau$
- ✓ Pre-selection (data from electronic detector)

  -vertex predicted in the emulsion

  -At least one negative track

  -1μ sample

  -0μ sample
- ✓ Emulsion Scanning

  -Scan back of selected tracks CS→SS→bulk→vertex plate

  -Vertex reconstruction & decay Search, NETSCAN

  -Event selection

  -Eye-Scan Check, visible recoil, blob or Auger electron
- ✓ Final kinematical cuts

  -decay length, kink angle, P_t at vertex

Backgrounds

1μ

- $\tau^- \to \mu^- \nu_\mu \nu_\tau$ (C1)
  - Charm mesons in $\nu_\mu(\bar{\nu}_\mu)$ and ν_e CC interactions

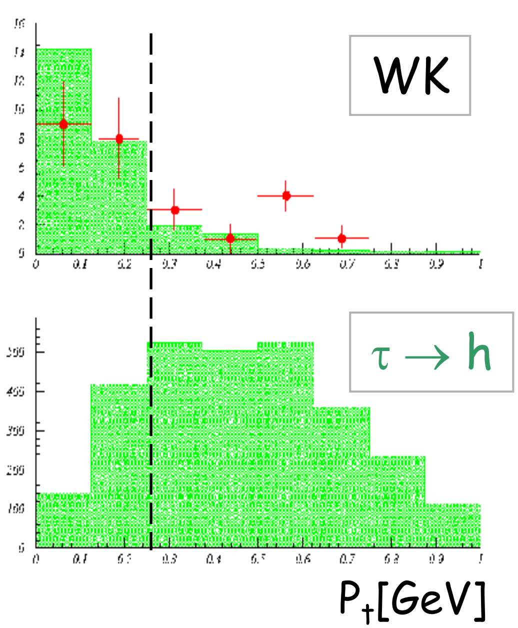
$\nu_{\mu/e}$ N $\to$ D$^-$ μ^+/e$^+$ X

- $\quad\quad \hookrightarrow \mu^-/h^-$ + neutrals $\sim 10^{-6}/N_\mu = 0.11$

0μ

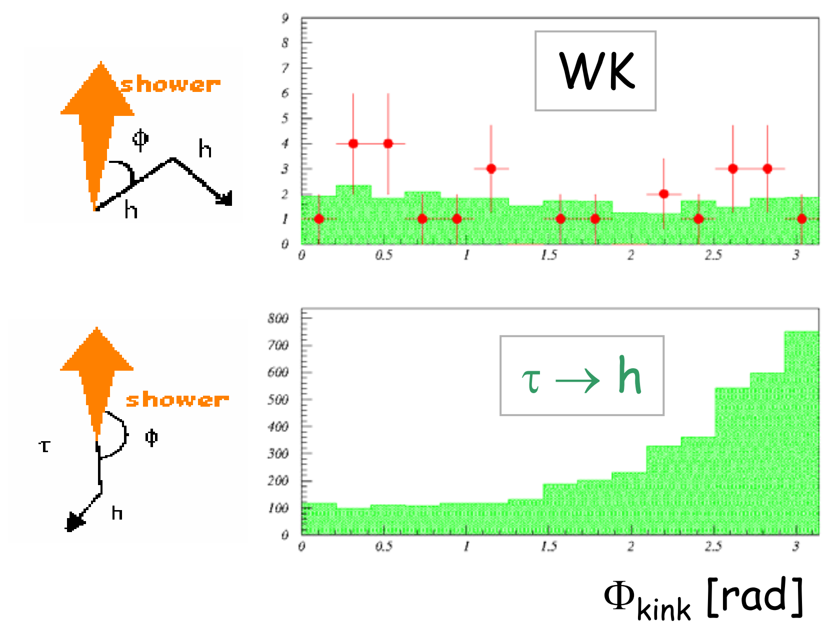
- $\tau^- \to h^-(nh^0)\nu_\tau$ (C1),
- $\tau^- \to h^+h^-h^-(nh^0)\nu_\tau$ (C3)
  - Charm production similar to μ channel
  - White interactions

White kink background



- 1-prong nuclear interaction with no ionising activity at the interaction point (fake τ decay topology)
- CHORUS measured :

$$\lambda_{WK}(P_T > 250\ \mathrm{MeV/c}) = 24.0 \pm 8.5\ \mathrm{m}$$



Post-scanning WK rejection for C3

Φ_t cut and $c\tau$ cut

Limit computation

DT infos	$\Delta\phi(rad)$	Background	N_τ^{max}	Data
$\tau \to 1\mu$		0.100 ± 0.025	5014	0
$\tau \to 0\mu\, C1$ [1994 – 1995 data taking]		0.300 ± 0.075	526	0
$\tau \to 0\mu\, C1$ [1996 – 1997 data taking]		51.5 ± 9.7	9447	59
No DT	$[0;\pi/2]$	23.7 ± 4.1	1754	30
	$[\pi/2;3\pi/4]$	6.7 ± 1.4	1415	14
	$[3\pi/4;\pi]$	11.9 ± 3.1	2856	10
$P_T < 250\ MeV/c$	$[0;\pi]$	4.6 ± 1.1	664	1
Charge -, $P_T > 250\ MeV/c$	$[0;\pi/2]$	0.820 ± 0.080	701	0
	$[\pi/2;3\pi/4]$	0.190 ± 0.020	714	0
	$[3\pi/4;\pi]$	0.090 ± 0.045	1230	0
Charge +, $P_T > 250\ MeV/c$	$[0;\pi/2]$	1.48 ± 0.30	13	3
	$[\pi/2;3\pi/4]$	0.58 ± 0.12	25	0
	$[3\pi/4;\pi]$	1.47 ± 0.40	75	1
$\tau \to 0\mu\, C3$ [1996 – 1997 data taking]		51 ± 12	4974	48
Low $c\tau$ ($< 75\mu m$)	$[0;\pi/2]$	9.5 ± 2.3	887	17
	$[\pi/2;3\pi/4]$	4.2 ± 1.0	875	6
	$[3\pi/4;\pi]$	5.6 ± 1.3	1740	4
High $c\tau$ ($> 75\mu m$)	$[0;\pi/2]$	16.7 ± 4.0	432	8
	$[\pi/2;3\pi/4]$	6.7 ± 1.6	376	8
	$[3\pi/4;\pi]$	7.9 ± 1.9	664	5

Limit computation

$N_\tau^{max} \equiv$ number of detectable ν_τ events if the oscillation probability is = 1

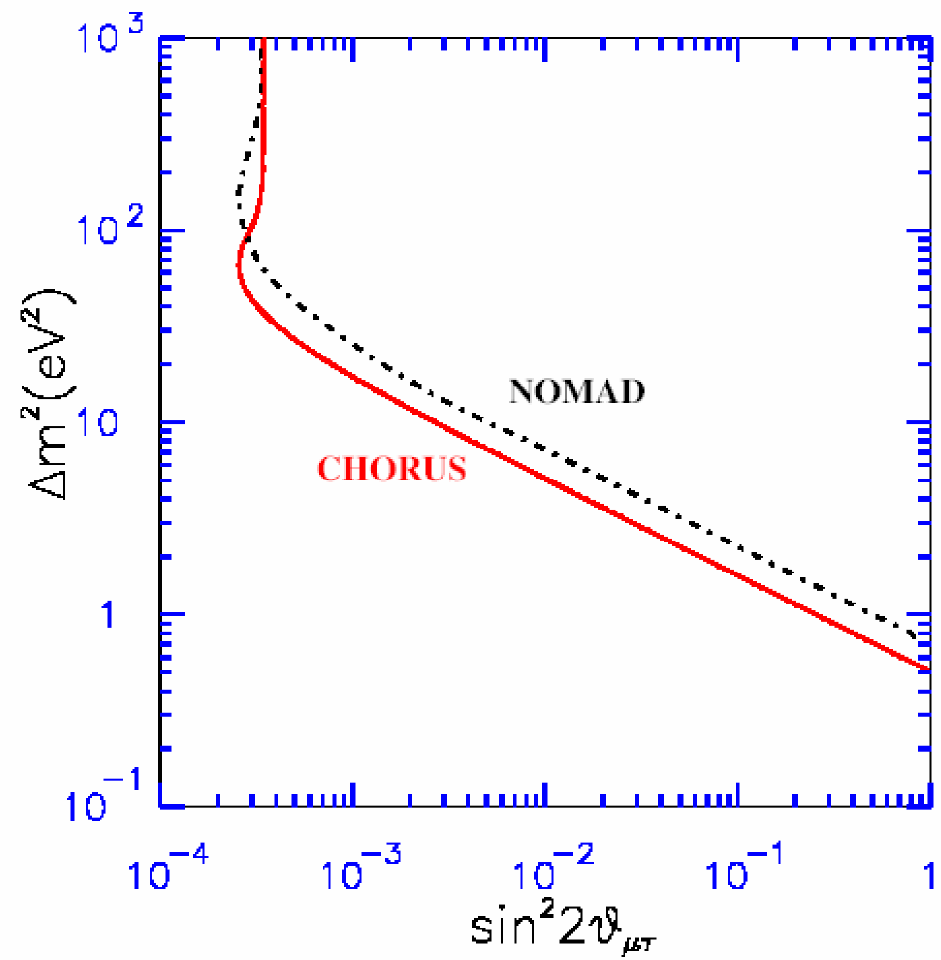
$$N_\tau^{max} = N_{loc}^{0\mu} \times \frac{\sigma_\tau^{CC}}{\sigma_\mu^{NC} \cdot \varepsilon_{loc\ 0\mu}^{NC} + \sigma_\mu^{CC} \cdot \varepsilon_{loc\ 0\mu}^{CC}} \cdot \sum_{i=1}^{4} BR(\tau \to i) \cdot \varepsilon_{0\mu}^{\tau \to i}$$

	bg	data	N_τ^{max}	
$0\mu C1$	51.5±9.7	59	9,447	Phase II
$0\mu C3$	51±12	48	4,974	Phase II
$1\mu C1$	0.100±0.025	0	5,014	Phase I
$0\mu C1$	0.300±0.075	0	5,26	Phase I

Feldman and Cousins unified approach
G.J. Feldman and R.D. Cousins
Phys.Rev. D57 (1998) 3873

Status of oscillation into ν_τ

This analysis excludes a region of the $\nu_\mu \rightarrow \nu_\tau$ oscillation with $\sin^2 2\theta > 3.4 \times 10^{-4}$ (at 90% CL) at high Δm^2.



$P_{\nu\mu \rightarrow \nu\tau} < 1.72 \times 10^{-4}$ @ 90% CL

$S_{\nu\mu \rightarrow \nu\tau}$: 2.5×10^{-4} @ 90% CL

$P(\leq L) = 28\%$

Conclusion

CHORUS still working on charm analysis.

- Measurement of associated charm production in neutral- and charged-current neutrino int.
- Measurement of the x-distributions of charmed particle production in neutrino interactions
- Measurement of Lambda_c production and decay into Sigma+ in neutrino interactions
- Measurement of diffractive production of D_s in neutrino interactions
- …………. **Are still in progress**